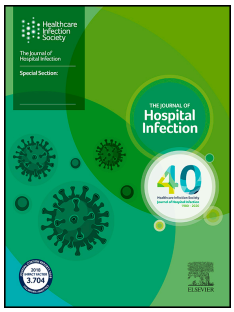
Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.



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The Dangers of Reused Personal Protective Equipment: Healthcare Workers and Workstation Contamination

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SUMMARY

Personal protective equipment is essential to protect healthcare workers (HCW). The practice of using reused personal protective equipment (PPE) poses high levels of risk for accidental contamination by healthcare workers. Scarce medical literature compares practical means or methods for safe PPE reuse while actively caring for patients. We observed 28 experienced clinical participants perform five donning and doffing encounters while performing simulated full COVID-19 patient evaluations. Participant N95 respirators were coated with a fluorescent dye to evaluate any accidental fomite transfer that occurred during PPE donning and doffing. Participants were evaluated using a blacklight after each doffing encounter to evaluate for new contamination sites and were assessed for the cumulative surface area that occurred due to PPE reuse doffing. Additionally, the participant's workstations were evaluated for contamination. All participants experienced some amount of contamination to their upper extremities, neck, and face. The highest cumulative area of fomite transfer risk was associated with the hook and paper bag storage methods, and the least contamination occurred with the tabletop respirator storage method. We found that storing a reused N95 respirator on a tabletop is a safer alternative compared to the current CDC paper bag storage recommendations. All participants donning and doffing PPE were contaminated. The results suggest that the current design of PPE required improved engineering and usability. PPE reusage practices pose an unacceptably high level of risk of accidental cross infection contamination to healthcare workers.

INTRODUCTION

Continued mutation of SARS-CoV-2 means that COVID-19 continues to be a cause of significant illness globally. Protective measure recommendations for health care workers (HCW) remain variable and sometimes ambiguous. HCW have anxiously relied on personal protective equipment (PPE) to protect themselves, their patients, and their families. Many HCW became infected while caring for patients due to errors in the use of, or insufficient PPE. There were 4,128 US HCW deaths attributed to COVID-19, and 115,000 deaths internationally, though the actual toll is likely greatly underestimated.[1,2] The CDC recommends a medical gown, gloves, respirator and eye protection for every encounter.[3] Unless stated explicitly, health care PPE is manufactured for single use only.[4] The current universal single-use equipment was not designed to be worn for prolonged time periods and can cause issues with increased headaches, workload, discomfort, overheating, distraction, and dehydration that necessitates frequent doffing.[5] However, due to increased demand and subsequent supply shortages, HCW have had limited access to PPE, especially during the early stages of the COVID-19 pandemic. Extended use and reuse of PPE are needed to meet this operational challenge with extended use considered the preferred method as it decreases the number of doffing cycles.[6] It is impractical to ask HCW to wear PPE for an 8-hour shift without removal as they require nutrition and restroom breaks and may encounter numerous situations that require multiple rounds of doffing during a typical 8-hour work shift.

Numerous studies have demonstrated that the process of PPE donning and doffing is difficult, variable, and often results in self-contamination after each use.[7,8,9] CDC guidelines recommend donning and doffing followed by disposal of contaminated equipment upon completion after a single use to minimize HCW pathogen exposure.[10] The outer surface of PPE

should be considered contaminated once exposed to a patient, and contact avoided during the doffing process.[11] The directions for PPE doffing focus on avoiding touching the outer surfaces, taking care to keep away from the body, and immediate disposal once doffed.[12] Since March 2020, there have been minimal changes to the CDC guidelines for PPE donning and doffing.[13] Importantly, the guidelines advise that institutions that reuse PPE should adjust their donning and doffing protocols according to local guidelines, which has led to wide variability in HCW PPE practices and exposure risks.[13]

There are very few studies regarding the safety profile of PPE reuse, recommendations for PPE reuse, or best practice guidelines on how to limit HCW fomite exposure between uses.[14] The CDC recommends a contingency strategy of placing used N95 respirators in a paper bag at the end of each shift for future reuse and rotating with other reused respirators.[6] The goals are to prolong the respirator life with the understanding that viable pathogens on the respirator will degrade and no longer be infectious.[6,15]

We investigated the effectiveness and safety of reusing PPE practices by evaluating the fomite transfer that can occur to HCW and their work areas while donning and doffing extended use, recycled PPE in a high-fidelity simulated ward. Our study population consisted of active HCW caring for hospital patients at the height of the COVID-19 pandemic.

METHODS

Participants, inclusion criteria

Nurses, advanced practice providers, and physicians were recruited from two academic hospitals. As this represented an exploratory study, participants were selected with at least 1 year of training and practice to reflect a level at which trainees are expected to assume responsibility

for routine COVID-19 patient assessment. Participants were recruited through email and word of mouth. Interested participants were provided with a written informed consent form that included the risks and benefits of the study. The inclusion criteria included active health care workers over the age of 18.

Simulation environment

We conducted a prospective study in a dedicated 30,000 square foot simulation center affiliated with a large public medical school in the United States. Each participant was assigned one fully furnished high-fidelity simulated emergency department exam room with an adjacent workstation located outside of the room that included the patient monitoring equipment used in the hospital. They were provided digital access to simulated patient records via a computer screen, keyboard, telephone, and the room had a bottle of hand sanitizer, and a wall hook to hang their personal protective equipment. An integrated audiovisual system recorded all activity digitally. The experimental environment has been validated and described in detail previously.[16,17]

Simulated contaminant and utilization

The study was conducted over 7 days in February and March 2021 at the height of the COVID-19 pandemic. We randomly assigned three respirator storage designation options to one of the available days. Participants were able to voluntarily sign up to minimize researcher bias or predictability.

The three respirator storage cohort options were a brown paper bag (Group A); a tabletop surface (Group B), or a computer monitor-mounted hook (Group C) (Figure 1).

The rooms were meticulously cleaned by the same investigator (DD) in a standardized manner between each patient encounter to reduce possible cross contamination and were

evaluated with a black light to ensure no traces of contaminant were left between each study subject's simulation.

We used fluorescent material that glows only if visualized under black light in prior PPE donning and doffing studies to validate our method and assess for fomite transfer.[16,17] A tablespoon of equal parts glogerm ™ and store brand petroleum jelly was applied to the outer surface of the N95 respirator to represent contamination, expected after a single use.[11] During pilot experimentation, this method of application was found to transfer only with direct contact, while providing for easy and consistent application. One half teaspoon of the combined mixture was applied by the same investigator (DD) to N95 respirators with a uniform standard coating every morning prior to participants arrival. Standard alcohol-based hand sanitizer was able to remove all traces of the fluorescent material. A black light was used to ensure a consistent layer was applied only to the outer surface, avoiding the PPE straps.

Participants were blinded to the fomite source, which was a nontoxic odourless mixture with minimal tactile perception and nearly invisible to the naked eye. Participants were examined prior to study participation under the black light for exposure to substances that might fluoresce before the data collection.

Simulation scenarios and patient evaluation

Participants were asked to perform five focused evaluations of simulated COVID-19 patients while reusing PPE. The CDC guidelines state, that unless otherwise indicated, the maximum number of times to safely don N95 respirators should be five as fit and function decline after multiple uses.[12,18] A note with vital signs and a chief complaint was placed on the door prior to each encounter. The participants donned their PPE prior to entering the room as per CDC and hospital guidance and were instructed to conduct a targeted history and examine a

high-fidelity mannequin (Figure 2**)**. Each scenario included an adult patient with COVID-19 symptoms requiring PPE donning and doffing for the encounter. Volunteer clinicians were instructed to perform as if they were in the middle of a shift. The PPE provided included 9500-N95 (lot# 070320), face shield, gloves and gown similar to that used by HCW every day. Participants were allowed to use new gloves and hand sanitizer as often as they felt necessary but were required to reuse all other provided PPE. All equipment needed for an examination, such as a stethoscope or otoscope, was available in the patient's room. Upon exiting the room participants would completely doff their PPE, hang the face shield and gown on the door, and store their respirator using one of the three randomly assigned methods.

The primary endpoint for the study was the amount of fomite transfer assessed using black light after each of the five scenarios. The contaminated areas were documented after every doffing event using our validated data collection tool. (Appendix 1) This tool was piloted and refined based on feedback from clinical users. The participants typed their focused history and physical exam note using the designated workstation computer. Once they completed their history and physical, the subjects would begin the process again by donning PPE in preparation for the next patient scenario. The patient room was thoroughly cleaned between patient encounter to avoid accidental contamination.

Data acquisition

Cumulative and new site areas of contamination were measured with a transparent ruler and blacklight. The workstation was examined under blacklight for any contamination sites without participant knowledge while the participants were in the patient room performing the patient history and physical. (Figure 3) The workstation contamination area was assessed using the data collection tool. (Appendix 1) Once participants completed doffing their PPE, they were

asked to close their eyes and stand in the standard anatomical position, (standing upright and facing forward with legs parallel and each arm hanging on either side of the body with the palms facing forward) while their clothing and body were examined by same investigator (DD) under blacklight for signs of contamination. The study subjects were then instructed to type their patient encounter note using the computer keyboard.

Black light measurements

Blacklight measurements were done looking for discreet locations of fluorescence as measured in cm^2 to account for the size of contamination that occurred on the workstation and on participants' bodies.[16] Areas of fluorescence were categorized as small ($<1cm^2$), medium ($\geq$1-$<2.5cm^2$); large ($\geq$2.5-$5cm^2$) or very large ($\geq 5cm^2$).

Study Oversight

The study was approved by the Indiana University institutional review board (IU IRB# 2005953971). All authors contributed to data collection and acquisition, database development, discussion, and interpretation of the results, and the drafting of the manuscript.

RESULTS

Study demographics and PPE training

Twenty-eight clinicians were recruited, resulting in 140 patient assessments; each participant completed all five patient scenarios. Females comprised 64% of the study population. Physicians comprised 53%, Nurse Practitioners 7%, and Nurses 39%. Half of the participants had been in independent practice three years or less. Most reported shift times of 9 or 12 hours. All participants were right hand dominant. Nearly all participants reported receiving numerous PPE trainings in the past year, and felt competent in safely donning and doffing PPE, though only 21% reported any direct training or discussion about managing reused PPE. 100% of participants indicated they would dispose of their PPE if it was visibly soiled or damaged.

Comparison of the 3 respirator storage techniques

All participants were evaluated for new contamination sites after each encounter. The paper bag, tabletop, and hook methods each had two participants that were able to don and doff in one out of the five encounters that did not result in a contamination. The hook method was used by one participant that was able to successfully don and doff three of the five episodes without contamination. Twenty of the 28 participants were contaminated after each PPE donning and doffing encounter. No participant was able to don and doff without being contaminated in the five encounters. (Table 1)

Table 1: Total number of contamination events for each storage method

Storage Methods	Number of contaminations	Total number of events	Contamination rate (%)
Paper bag	48	50	96
Tabletop	43	45	95
Hook	40	45	88
Total	131	140	93.6

The right arm had the greatest number of small fomite sites for the paper bag and hook methods; however, the tabletop storage method had the greatest number of contaminated small sites on participants' heads. Additionally, the areas with the largest areas of fomite transfer were on the head, neck and trunk. (Figure 4)

Comparison of cumulative contamination sites

The cumulative contamination that occurred over the course of all five patient encounters was assessed, in addition to reviewing the number of new contamination sites after each patient encounter. The total surface area contamination was least when the respirator was stored using the tabletop method (Table 2).

Table 2. Average surface area contamination after five patient encounters*

	Very Large	Large	Medium	Small
Paper bag	13cm^2	10.8 cm^2	23.3 cm^2	19.5 cm^2
Tabletop	6.7 cm^2	7.8 cm^2	16.9 cm^2	15.8 cm^2
Hook	14.4 cm^2	10.8 cm^2	20 cm^2	19.8cm^2

*Contamination area: small <1cm²; medium ≥1-<2.5cm²; large ≥2.5-5cm²; very large ≥5cm²

Cumulative sites- comparison of the 3 storage techniques

The results are shown in Table 3 and Figure 5. There was a gradual increase in contamination on the head, neck, and trunk areas with all storage methods. There was more variation in contamination of the two arms.

Table 3: Average areas of total contamination over 5 encounters using each of the three different storage methods

Storage method	Anatomic site	Encounter 1	Encounter 2	Encounter 3	Encounter 4	Encounter 5
Paper bag	**Head**	36 cm^2	68.5 cm^2	71 cm^2	84 cm^2	96 cm^2
	Neck	48 cm^2	70 cm^2	92.5 cm^2	107.5 cm^2	111.5 cm^2
	Trunk	35 cm^2	39 cm^2	44.5 cm^2	49 cm^2	74.5 cm^2
	Right Arm	72 cm^2	78.5 cm^2	89 cm^2	83.5 cm^2	92.5 cm^2
	Left Arm	85 cm^2	73 cm^2	56 cm^2	71.5 cm^2	63 cm^2
Table top	**Head**	49.5 cm^2	79 cm^2	91 cm^2	94.5 cm^2	88.5 cm^2
	Neck	24.5 cm^2	45 cm^2	45.5 cm^2	43 cm^2	52 cm^2
	Trunk	24.5 cm^2	33.5 cm^2	41.5 cm^2	46.5 cm^2	39.5 cm^2
	Right Arm	34 cm^2	35.5 cm^2	37.5 cm^2	33 cm^2	30 cm^2
	Left Arm	51.5 cm^2	61cm^2	37.5 cm^2	38 cm^2	35.5 cm^2
Hook	**Head**	52 cm^2	72 cm^2	81 cm^2	86 cm^2	99 cm^2
	Neck	20 cm^2	32 cm^2	46.5 cm^2	61.5 cm^2	67.5 cm^2
	Trunk	40 cm^2	61 cm^2	65.5 cm^2	61.5 cm^2	78 cm^2

	Right Arm	82 cm^2	83cm^2	115.5 cm^2	73 cm^2	81.5 cm^2
	Left Arm	62.5 cm^2	52 cm^2	46.5 cm^2	53.5 cm^2	52.5cm^2

Internal respirator contamination

At the end of five patient encounters, each participant placed their respirator on their workstation. The respirators were evaluated by same investigator (DD) with a black light for any inside contamination. The hook method was the least internally contaminated (50%), compared with 88% and 75% for the paper bad and tabletop methods, respectively.

Workstation contamination

Of the 28 participants, 85.7% had some form of workstation contamination at the end of the five encounters. The areas with the most notable contamination were the keyboard (spacebar and middle keys) and the counter areas near the keyboard that were used for the tabletop respirator storage cohort. The tabletop was the only method to have very large contamination though the contamination was confined to the area of respirator storage and was dependent on whether the outside portion of the N95 respirator was placed down against the tabletop. The paper bag method had the most overall number of small contamination sites. (Figure 6)

DISCUSSION

We found wide variations in the donning and doffing of PPE practices by HCW across different simulated patient encounters. All three methods utilized for respirator storage between doffing and donning episodes resulted in a significant amount of contamination to the HCW participants and to their workstations. A new contamination was found in 75% of participants after each patient encounter, and by the end of five donning and doffing cycles 100% of

participants had some form of fomite contamination. The fomite contamination to the head, neck, and trunk gradually increased during the five patient encounters. However, the arms had notable variation in comparison to the other body area locations. The total surface area of contamination was greatest with the paper bag and hook methods of PPE storage, and least with the tabletop method. Additionally, a significant proportion of participants had fluorescent contamination on the inside of their N95 respirators; remarkably, the hook storage method demonstrated the least contamination of the three storage methods. Finally, in 24 of the 28 study participants (85%), the workstations were contaminated by fomite transfer at the end of the five cycles.

The results of this study demonstrate the cross infections risks to HCW associated with reusing PPE. The area most affected by small areas of contamination was the right arm (all participants being right-hand dominant). The areas of smallest contamination on the rest of the body were significant as they represented areas accidently exposed to contamination, with some of these areas developing into much larger contamination sites from repeated additive exposure during the five encounters.

This study also demonstrated that certain respirator storage methods are riskier for contamination than others. All three PPE storage methods had cumulative increases as the study progressed in total surface area contamination to the head, neck, and trunk regions. Interestingly, right and left arm contamination was a variable which was attributed to the amount of hand sanitizer utilized. In the pilot phase of the study, hand sanitizer would easily remove hand fluorescence so this likely represents real world contamination variability that is affected by how HCW use hand sanitizer. Unfortunately, other vulnerable areas, such as the head and neck that aren't routinely cleaned during clinical shifts are at risk of cumulative contamination from potential pathogens.[19] Additionally, some areas that were initially small expanded into larger

areas of contamination over the course of the five simulated encounters. Intuitively, this could be an expected result of HCW repeatedly exposed to a contamination that was not immediately addressed. Our results indicate that storing a reused N95 respirator on a tabletop face up during a shift could be a better alternative to the current recommended CDC paper bag recommendations.

Another important finding was the number of respirators that had contamination on their inside surfaces. It should be clear that the contamination was not apparent to the naked eye, similar to aerosol contamination by airborne pathogens.[5] Inside-respirator contamination likely occurred through accidental direct hand contact and through facial contamination that was then transferred to the respirator. This represents a serious risk to HCW from reusing a N95 respirator because of the high risk of self-contamination and infection. The hook method performed best in this regard, perhaps not unexpectedly given that this method facilitates handling ot the respirators by the straps.

The workstation with the most overall contamination was noted when the CDC-recommended paper bag method was used. The act of repeatedly reaching into a paper bag holding a contaminated respirator could explain this. Interestingly, the tabletop method, which placed the respirator directly on the workstation work site, led to a much lower number of contaminated areas of the workstation, but the contaminated areas were much larger.

The study focus was on evaluating HCW self and workstation contamination, but unfortunately, contamination and its risk of further transfer does not occur in a vacuum. Any residual contamination to a HCW must be considered as a serious risk to patients and other HCW. Anecdotally, while cleaning the patient exam room between encounters, we observed fluorescent transfer to the nasal canula, patient wrists and to the handrails of the bed. These areas

were thoroughly cleaned to limit external areas of potential contamination to the study subjects. In real world care, this contamination source would be a risk to patient and staff safety.

LIMITATIONS

The study was undertaken at a time during the COVID-19 pandemic when PPE supplies were extremely limited, meaning that HCW were already familiar with PPE reuse; at the outset of any future pandemic HCW unfamiliar with PPE reuse might perform worse than we observed. The simulated context of our study represents a potential confounder in that staff may be less careful than when having patient contact. Nevertheless, simulation offered access to events that can otherwise not be directly observed, and in a safe and controlled environment.[20] We used structured scenarios that set up specific settings that evoke and replicate features of real-world clinical situations during COVID care, with the aim of producing data that can be analyzed for improving HCW wellness.[21] To increase the external generalizability of our findings, we allowed variability in the HCW workflow to replicate current clinical practice during the pandemic. However, although we used high fidelity simulation, participants were aware they were being evaluated and the Hawthorne effect may have applied. The glo-germ™ was used as the measure of contamination, and it cannot be concluded that our observations would apply to the transfer of infectious virus. Additionally, patients will have variable levels of viral load depending on severity and type of disease, and the burden of respirator contamination in real life settings may be limited by the use of visors, or by particles being trapped in the respirator. Finally, this study was conducted in the US where N95 respirators were commonly used but may not represent the PPE usage in other countries.

CONCLUSIONS

The study demonstrated deficits in PPE reuse among all observed healthcare provider subjects, with a significant amount of contamination found when PPE is reused and stored by any method, including the paper bag method recommended by the CDC. There is still no reputable evidence to guide HCW on how to approach PPE reuse during clinical care. We found that the main contaminated areas were the dominant arm, head, and neck. There was no clearly superior storage method for respirators during shifts, although placing respirators on a hook or leaving on the tabletop seemed preferable to the current CDC-recommended paper bag storage method. High areas of contamination should be taken into consideration when re-designing PPE, physical space design of clinical wards and better ways for HCW to safely reuse PPE.[22] Future studies should focus on practical doffing methods for reused PPE while incorporating a deeper appreciation of human factors to support safe and consistent doffing practices.[23]

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Conflict of interest statement: None

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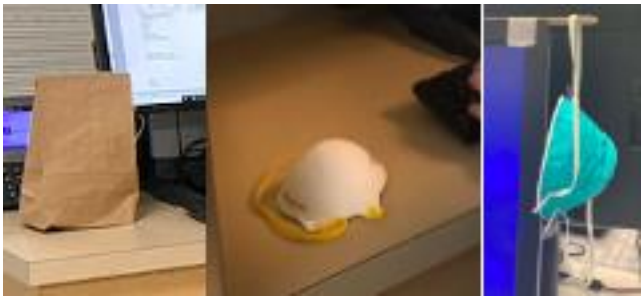
FIGURE 1: PPE storage methods



A: paper bag ; B: tabletop; C: monitor hook

Figure 2. Nurse participant performing a physical exam on a high fidelity mannequin

Figure 3. Workstation data collection utilizing a black light

Figure 4: Total numbers of new site contamination sites after five encounters using each of the three storage methods

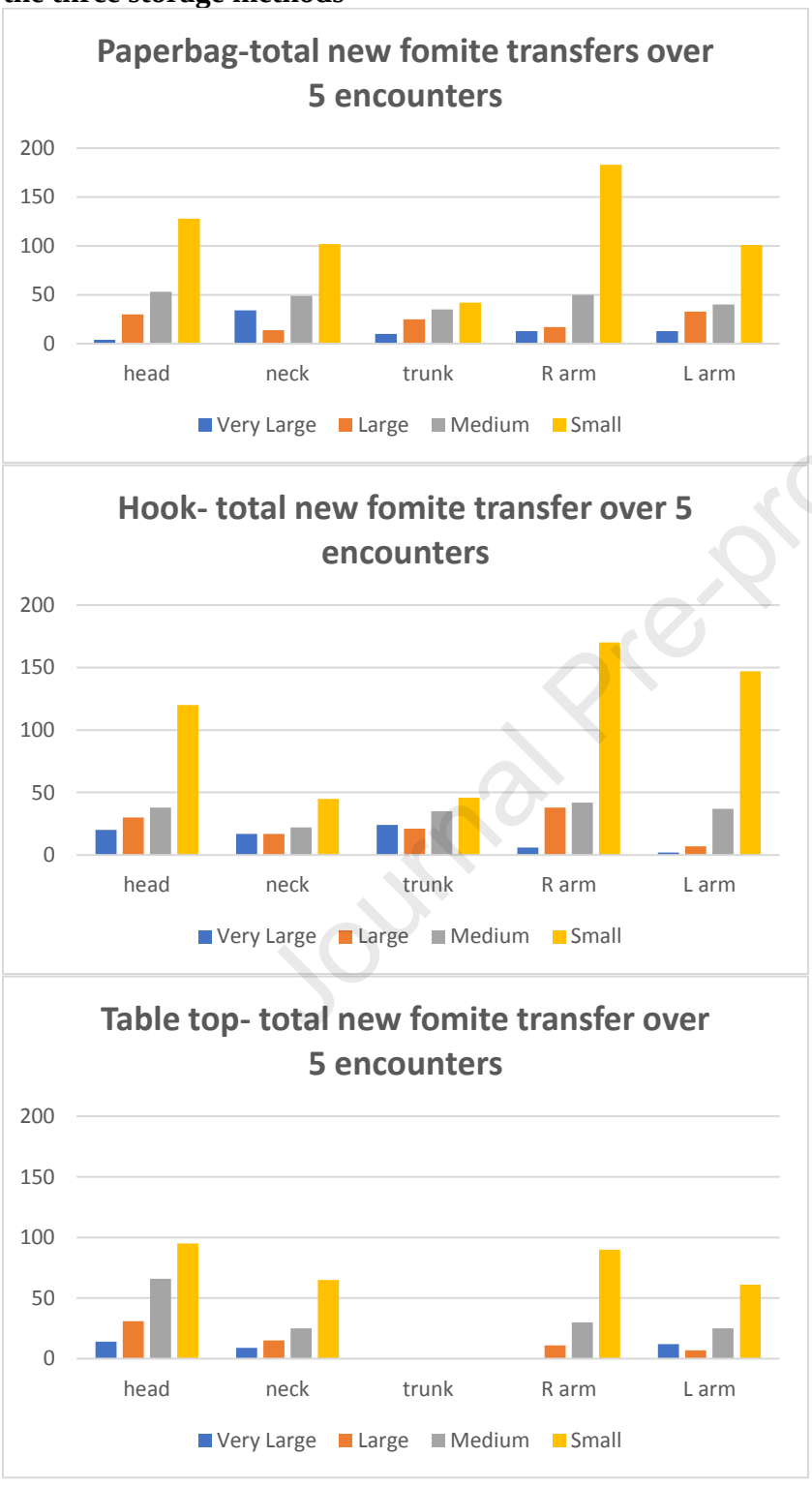


Figure 5: Ttotal surface area contamination from encounter 1 to encounter 5 using each of the three storage methods

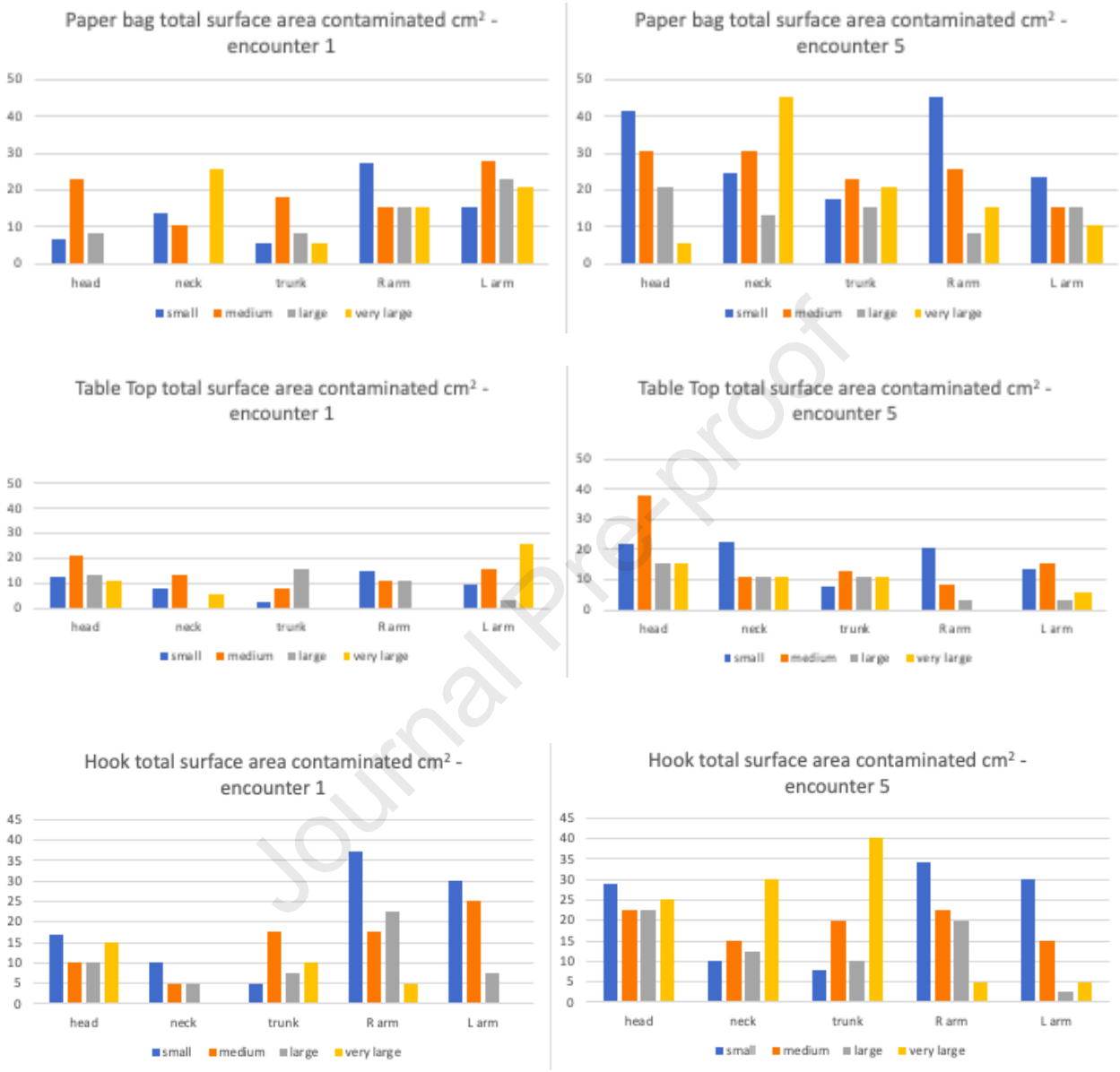


Figure 6: Workstation contamination by storage method